Liquid Dielectric Constant Measurement Based on Thickness Shear Mode Quartz Resonators

Chao Zhang and John F. Vetelino
Laboratory for Surface Science and Technology,
University of Maine, Orono, ME 04469

Thickness shear mode (TSM) bulk acoustic wave (BAW) devices have been widely used for liquid mechanical property measurement, such as density and viscosity. However, no result has been reported on employing the TSM sensor for liquid dielectric constant measurements. This is due to the fact that the conventional quartz crystal microbalance (QCM) sensors are not sensitive to the liquid electrical property changes because their electrode geometry shields most of the electric field associated with the TSM from penetrating into the contacting liquid. Since liquid dielectric constant measurements are very important for many industrial process control and environmental monitoring applications, such as the water quality monitoring, fuel mixing ratio detection and oil deterioration and contamination measurements, it is the purpose of this paper to present a novel liquid dielectric constant sensor based on TSM quartz resonators.

In the present study, a series of 5MHz AT-cut TSM resonators with different electrode configurations have been developed to allow significant penetration of the TSM electric field into the contacting liquid. Fig.1 shows the electrode geometry of the devices. The dielectric liquid chosen to be the measurand of interest is a non-conductive 2-propanol solution of varying concentrations. A commercial oscillator was used to drive the resonators and the output frequency was measured and compared to results obtained using a 5 MHz AT-cut conventional QCM.

Fig. 2 (a) shows the frequency shift of the sensors with different electrode geometries as a function of 2-propanol concentration (weight percent), where the resonant frequency in water is used as a reference. It is known that the density viscosity product of 2-propanol solutions increases with the concentration and reaches its maximum at about 50% (weight percent), while the dielectric constant of the solution keeps decreasing from about 80 of pure water to about 20 of pure 2-propanol*. The frequency decrease of the standard resonator is due to the increase of the density viscosity product, since the standard resonator is not sensitive to the liquid dielectric constant changes. However, the frequency response of the resonators with novel electrode configurations is influenced both by the liquid mechanical property and dielectric constant changes. The increase of the resonant frequency of these resonators demonstrates that they are sensitive to the change of the liquid dielectric constant.

Assuming the sensitivity of the resonators with novel electrode geometries to the liquid mechanical property changes are the same as the standard TSM resonator, one can obtain the frequency shift due to the change of the liquid dielectric constant by subtracting the frequency change of the standard QCM in Fig.2 (a). The result is shown in Fig.2 (b). It can be seen that the resonant frequency of the resonators increases when the liquid dielectric constant decreases. Also resonators with different electrode configurations show different sensitivity to the liquid dielectric constant changes. This is due to the fact that different electrode geometries have a different area of metallic contact on the surface of the resonator, which influences the penetration of the TSM electric field into the solution, hence the sensitivity to the liquid dielectric constant.

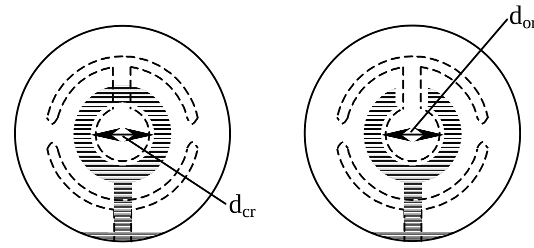
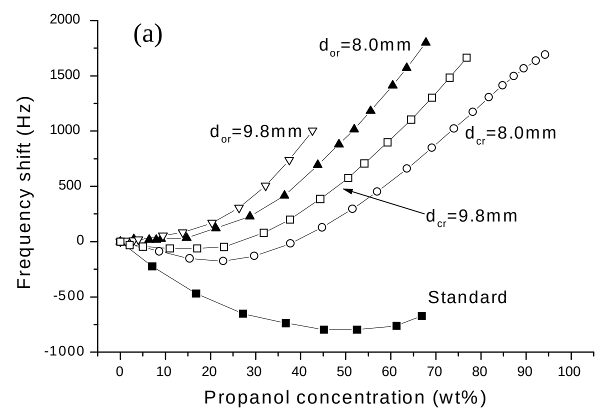
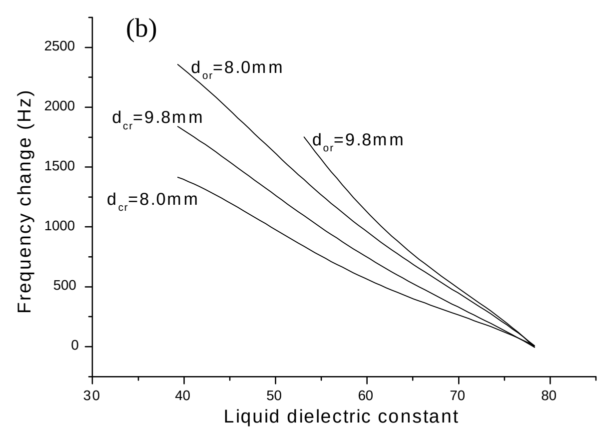


Fig.1 Electrode configurations of the TSM resonators.
(a) The closed ring geometry with d_{cr}=8 and 9.8 mm;
(b) The open ring geometry with d_{or}=8 and 9.8 mm.

Fig.2 Frequency shifts of 5 MHz TSM resonators with different electrode geometries as a function of (a) 2-propanol concentration and (b) liquid dielectric constant.





* CRC Handbook of Chemistry and Physics, 1980.